Center of Excellence for the Synthesis and Processing of Advanced Materials: Review – June 3, 2004

"Defect Structures and Properties in Rare-Earth-Ba-Cu-O Cuprate Superconductors"

David O. Welch

Brookhaven National Laboratory

Project Coordinator

BROOKHAVEN NATIONAL LABORATORY

A Project of the Center of Excellence for the Synthesis and Processing of Advanced Materials:

"Defect Structures and Properties in Rare-Earth-Ba-Cu-O Cuprate Superconductors"

Participating Institutions:

Ames Laboratory, Argonne National Laboratory,

Brookhaven National Laboratory, Oak Ridge Laboratory,

Los Alamos National Laboratory, and Sandia National Laboratory

Project Coordinator:

David O. Welch, BNL

CSP Review: "Defect Structures… in Cuprate Superconductors"

This project involves groups funded by BES and/or the "Superconductivity for Electric Systems" program, Office of Electric Transmission and Distribution.

Project Objectives

To understand the origin and effects on superconductivity of defects and nanoscale structure in RE-123 phase cuprates and state-of-the-art conductors which utilize them.

Active Collaborative Projects

- Basic Properties of RE-123 Compounds
  - Substitution Effects on Superconductivity
  - Oxygenation Thermodynamics and Kinetics

  Ames: McCallum, Kramer   ANL: Veal, Claus

  BNL: Welch, Su (Caltech)

- Defect Structures and Critical Currents in YBCO Coated Conductors

  ANL: Miller, Veal   ORNL: Goyal, Christen, Feenstra, Lee

  BNL: Suenaga, Welch   LANL: Holesinger, Foltyn

  SNL: Clem, Siegal

Activities

- "Caucuses" at Fall MRS (November 2003);
  "Superconductivity for Electric Systems" Peer Review (July 2004)

- Review articles on state-of-the-art
  - Thickness Dependence of J_c in coated conductors
  - Buffer layers
  - Oxygenation

Some Research Highlights

- Coated Conductors
- Oxygenation
- Critical Currents

Coated Conductors

- Coated Conductor Architecture:

  Buffer Layers and Defects

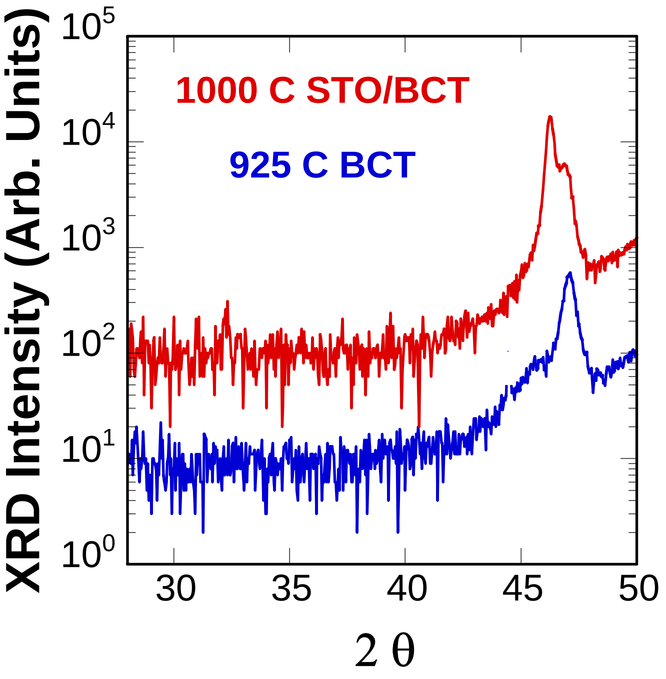
  ORNL, LANL, SNL, BNL

SNL - LANL Collaboration
Buffer Layer Defects Propagating into YBCO

M. Siegal and P. Clem: Sandia
T. Holesinger: Los Alamos

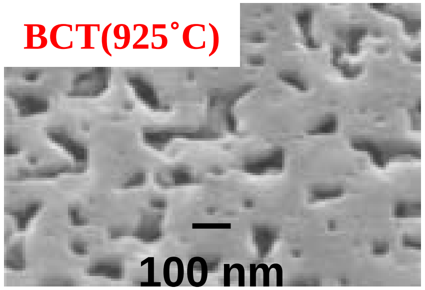
Motivation: Develop an <u>all sol-gel</u> process for both <u>buffer</u> and <u>YBCO</u>

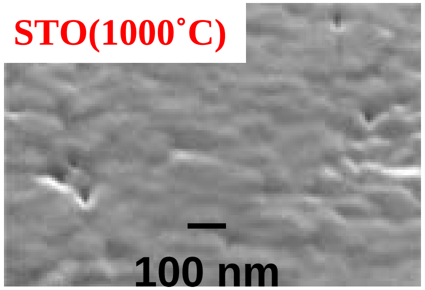
To date: $Ba_{0.2}Ca_{0.8}TiO_3$ is an excellent template layer for c-axis $SrTiO_3$ on W-doped Ni(100) tape.



<u>Lotgering factors</u>
BCT > 0.995
STO > 0.991

STO alignment/morphology is excellent. However, YBCO growth results in poor J_c. Why?





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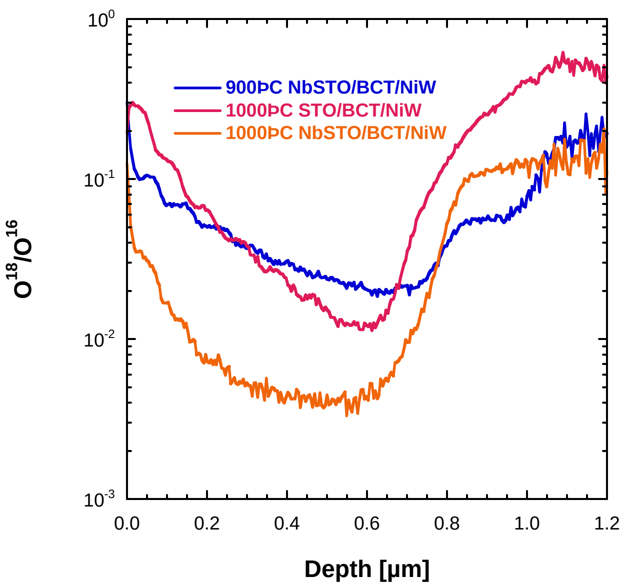
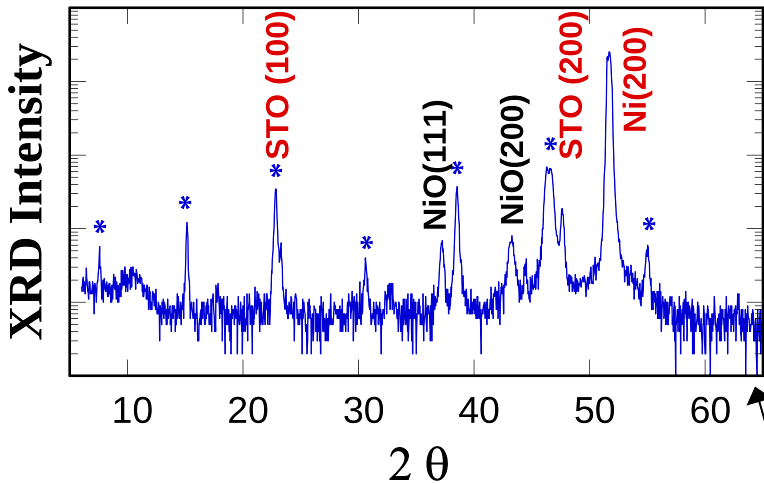
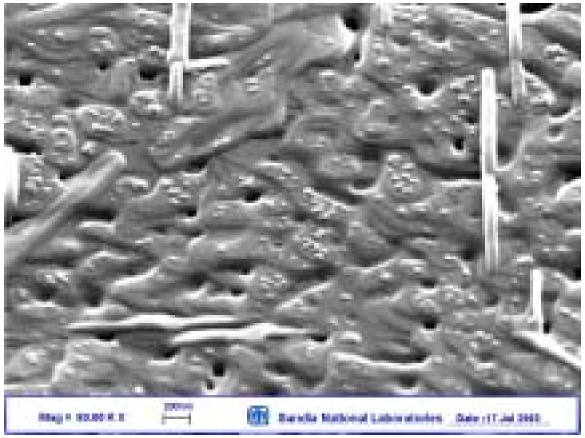
Evidence for good STO oxygen diffusion barrier and sufficient YBCO c-axis orientation and morphology

SIMS results show:
Nb-doped STO is an excellent oxygen diffusion barrier!







YBCO c-axis orientation and morphology are typical for high J_c films.

But J_c < 0.5 MA/cm^3! *WHY?*

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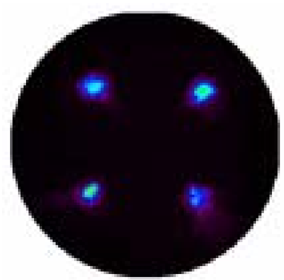
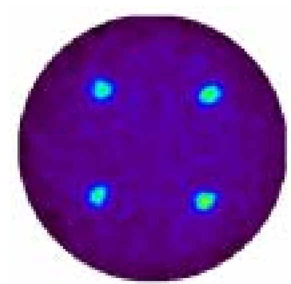
In-Plane Texturing Degrades due to High Lattice Mismatch between Ni and BCT/STO

NiW (220)



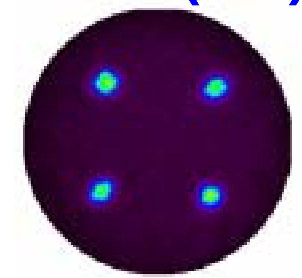
FWHM = 6.6 degrees

STO (220)



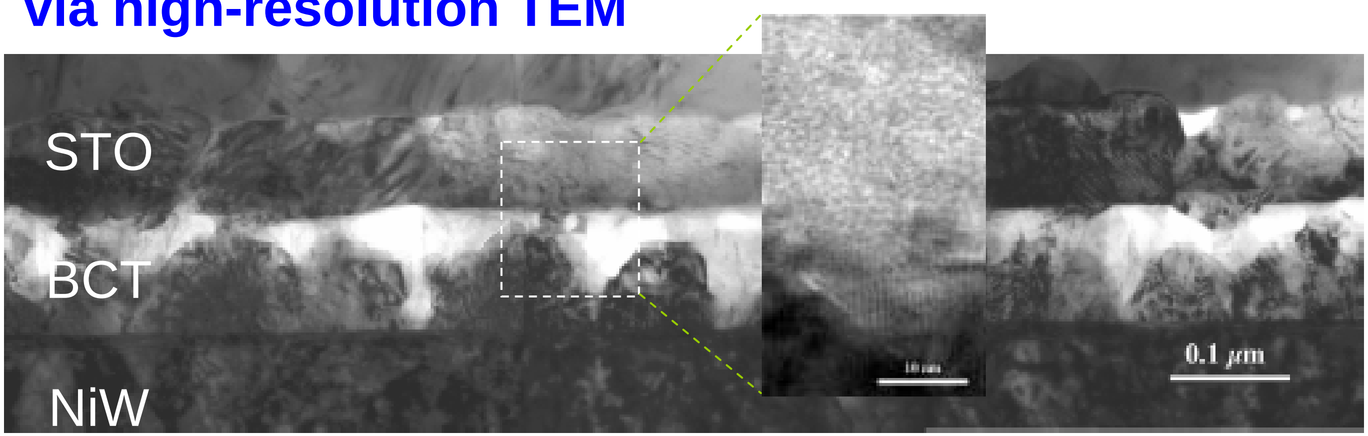
FWHM = 8.6 degrees

YBCO (103)



FWHM = 8.9 degrees

Understanding defect propagation from BCT into STO into YBCO via high-resolution TEM



Average grain boundary angles cannot support high J_c's (Dimos).

Must improve texture of BCT template layer on Ni!

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Coated Conductors

- The BaF_2 process for ex-situ YBCO growth
  ANL, BNL, ORNL, SNL, LANL
  - Growth and Characterization
  - Thickness Dependence of J_c

Reel-to-reel characterization of YBCO coated conductors: Formation of YBCO from “BaF_2” precursor

PI’s: ANL – V.A. Maroni ORNL – D. F. Lee

Objectives: To study ex-situ YBCO formation using complementary R2R XRD and Raman techniques.

To investigate the possibility of using these techniques for in-situ monitoring.

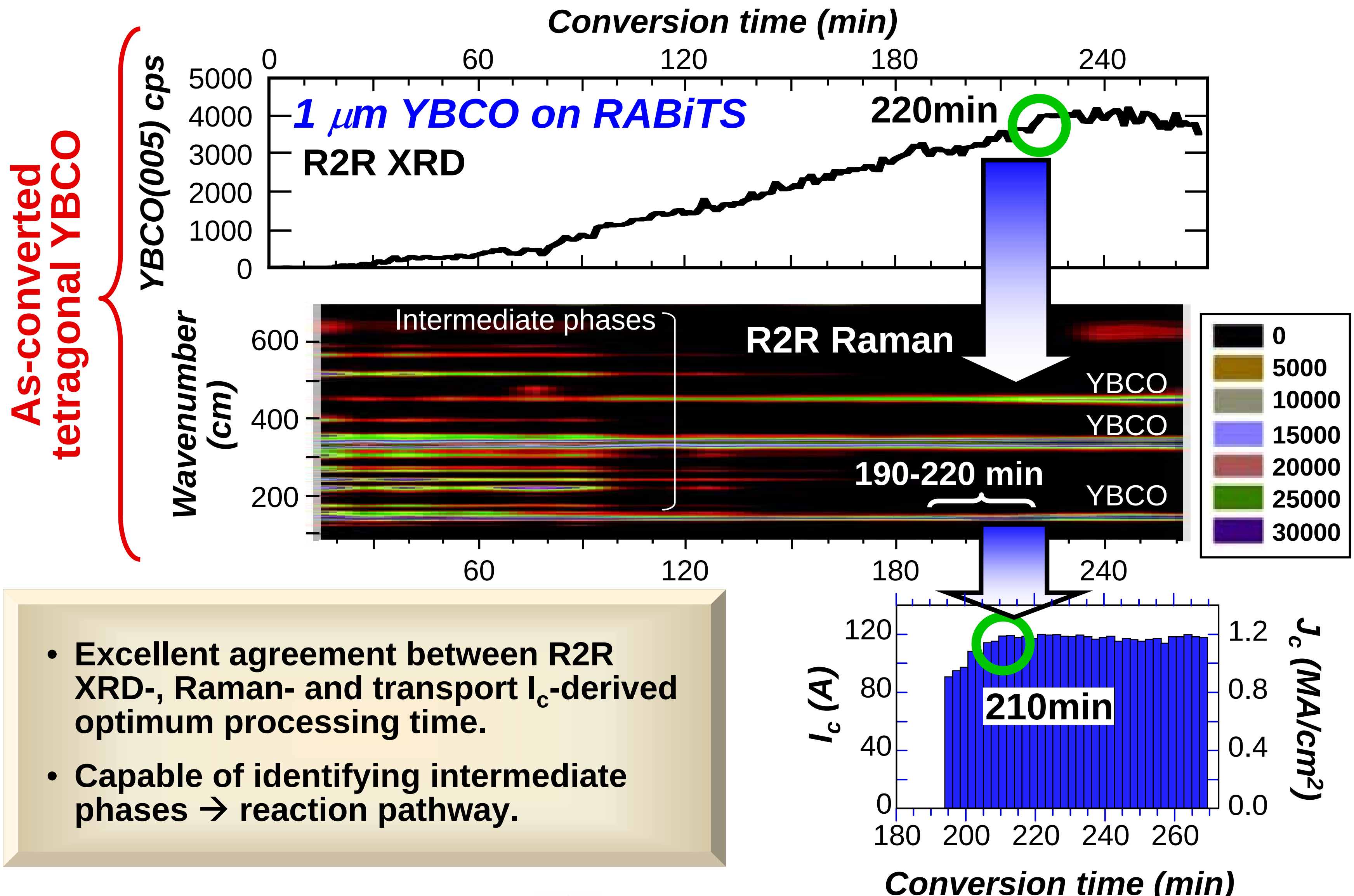
Samples: Ex-situ YBCO on RABiTS with graded YBCO phase assemblage along length of the tape.

Enables R2R examination of phase development in a single sample.

R2R XRD:

R2R Raman:

XRD and Raman microscopy are being studied as potential feedback control techniques



- Excellent agreement between R2R XRD-, Raman- and transport I_c-derived optimum processing time.
- Capable of identifying intermediate phases → reaction pathway.

Results indicate that these techniques may be used as in-line diagnostic tools for manufacturing

Accomplishments:

- Developed and tested a method for creating a graded Y-Ba-Cu-O phase assemblage on a single "BaF_2" precursor tape.
- Demonstrated that XRD and Raman can provide complimentary information on the processing, texture and phase development of ex-situ coated conductors.
- Work has been cited as "an exemplary national laboratory collaboration and utilization by industry partners" by DOE Peer Review committee.
- Received "Significant Strategic Research Accomplishment Award" for the 2003 DOE Superconductivity Program Peer Review.

Significance:

- Process monitoring and control strategies of the DOE Coated Conductor Development Roadmap have stressed the importance to develop in-line in situ control techniques for large scale manufacturing.
- We have identified XRD and Raman as potential candidates as well as the type of information each technique can provide.

Oxygenation of RE-123 Compounds and Conductors

- Oxygenation:

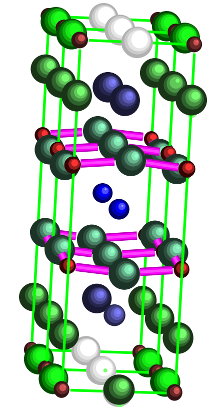
  ANL: "Oxygenation of coated conductors and bicrystals" Veal, Claus

  AMES: "$R_{1+X}Ba_{2-X}Cu_3O_{7+\delta}$ Compounds" McCallum, Kramer

  BNL: "Theoretical analysis of oxygenation thermodynamics and kinetics" Welch

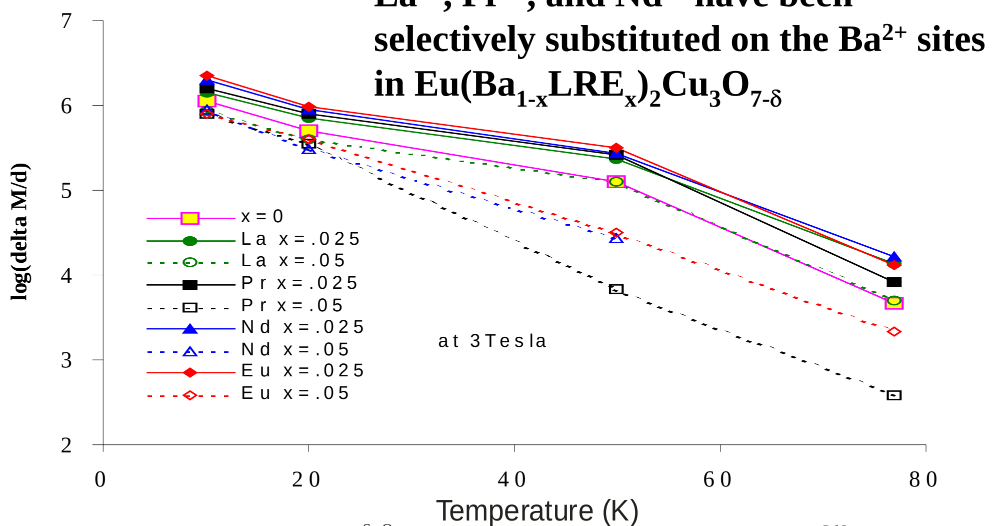
AMES LABORATORY

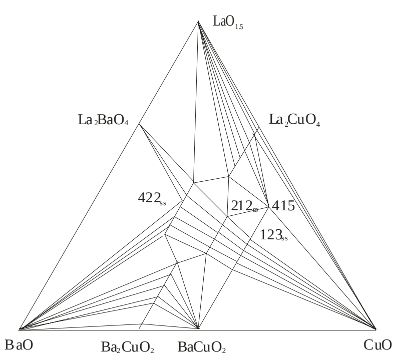
$R_{1+x}Ba_{2-x}Cu_3O_{7+\delta}$
R = La, Pr, Nd, Sm, Eu and Gd

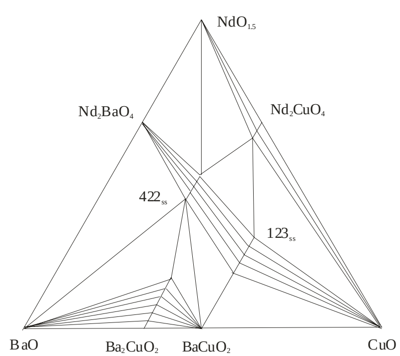


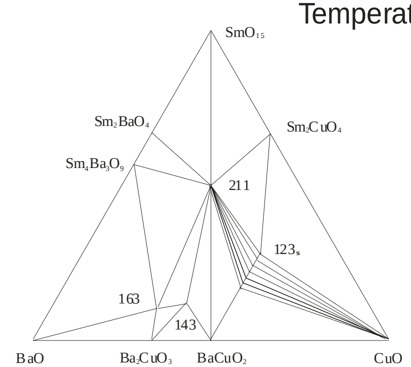
- J_c can be varied with R and x
  - At low concentrations of R^{3+} defects enhances J_c at high temperature and field
- The degree of O defects is dependent
  - Excess R^{3+}
  - PO_2 of the Processing

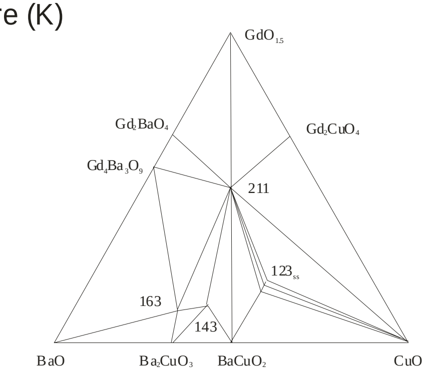
La^{3+}, Pr^{3+}, and Nd^{3+} have been selectively substituted on the Ba^{2+} sites in $Eu(Ba_{1-x}LRE_x)_2Cu_3O_{7-\delta}$



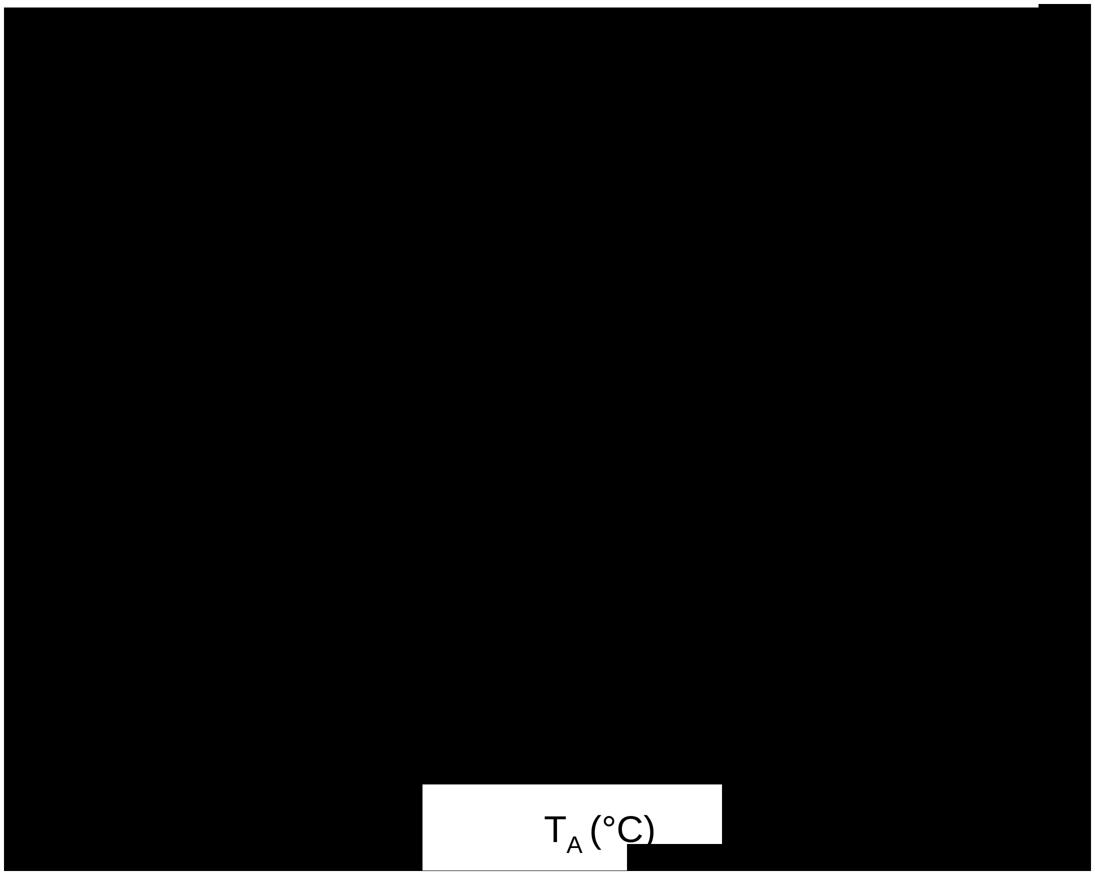








Control of oxygen stoichiometry in $YBa_2Cu_3O_x$ coated conductors



Stoichiometry is controlled by the annealing temperature T_A

Superconducting T_C becomes maximum at T_A = 450 °C

However, J_C increases systematically with increasing stoichiometry (decreasing T_A)

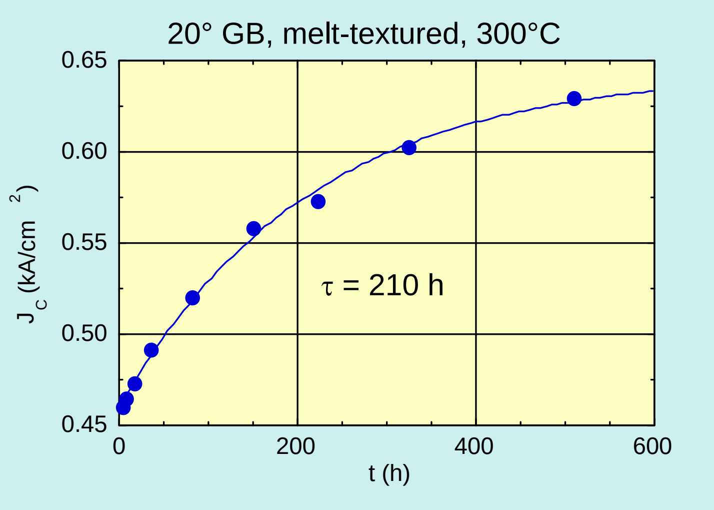
Novel technique permits reversible control of oxygen stoichiometry in YBCO films

YBCO films prepared by ISD

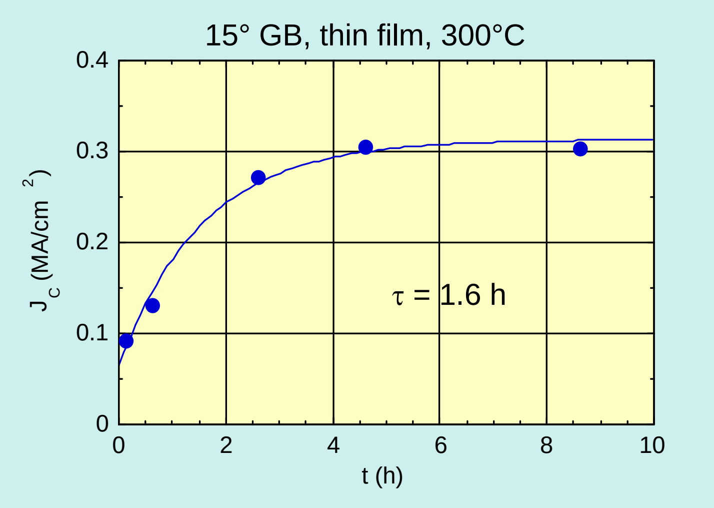
Oxygenation of grain boundaries in bulk and film samples

Oxygenation of thin-film GBs is much faster than bulk GBs

Bulk grain boundary



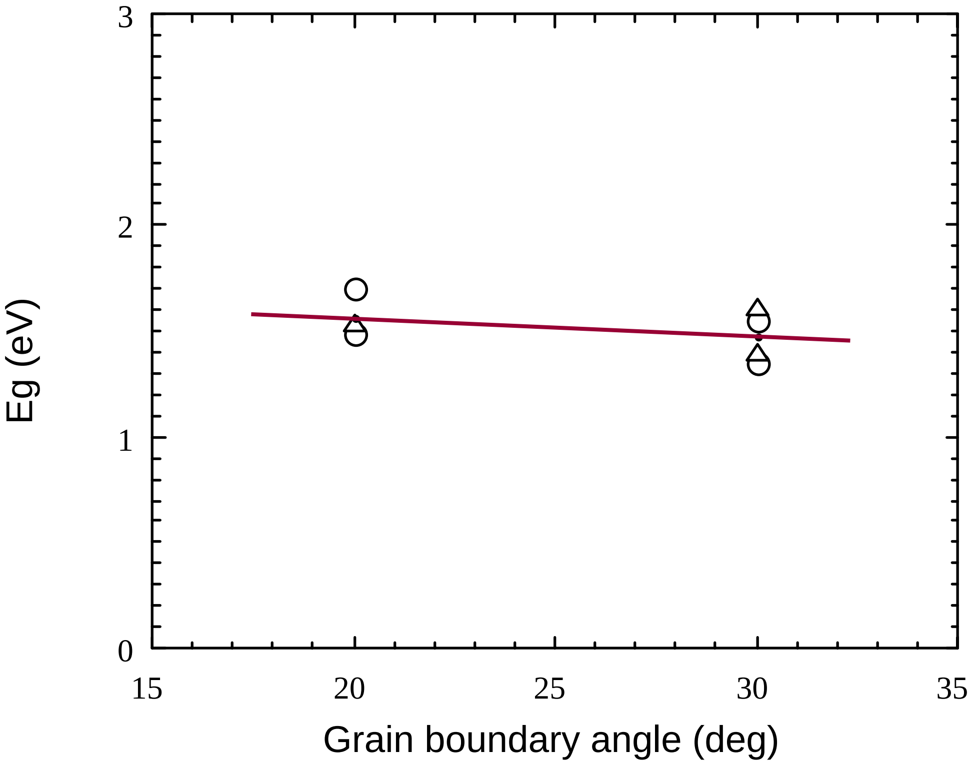
Thin film grain boundary



Samples were initially equilibrated at 450° in flowing O_2. They were then oxygenated for various periods at 300°C. $J_C(t) = J_{C0} + \Delta J_C (1-\exp(-t/\tau))$

• Oxygenation of thin-film GBs is 100 times faster than bulk GBs

Activation energy for oxygen diffusion into grain boundary



Activation energy $E_g \sim 1.5$ eV

E_g relatively independent of GB misorientation angle

Oxygenation of [001] tilt grain boundaries in melt textured YBCO

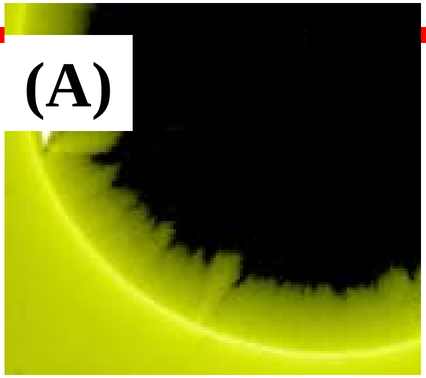
Critical Currents

- Thickness Dependence of J_c in Thick Film Conductors
  - ORNL, LANL, Wisconsin
  - BNL, LANL

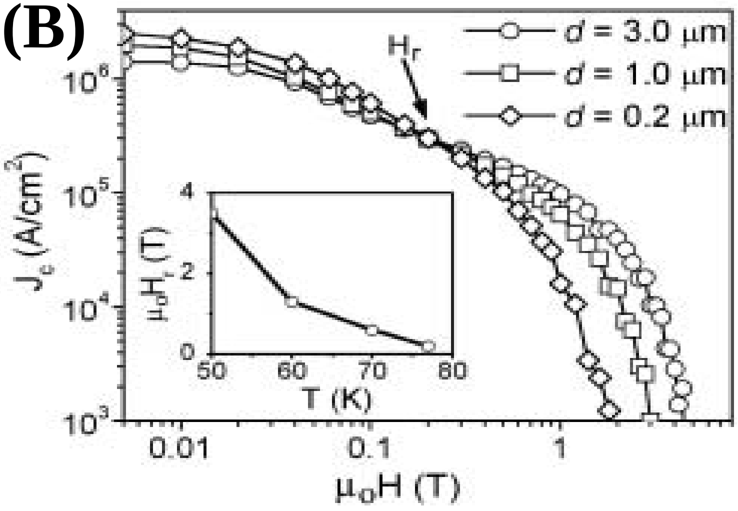
Thickness dependence of Critical Current Density $J_c(T, H)$ of $YBa_2Cu_3O_7$ thick films

Q. Li, Z. Ye, and M. Suenaga/**BNL**   S. R. Foltyn, and H. Wang/**LANL**

(A)



(B)



Results: A surprising crossover was found in critical current densities of “uniform” YBCO films with different thicknesses in magnetic fields.

Practical significance: Self-field transport critical current measurements, which are commonly used for YBCO coated conductors, are not a sufficient characterization.

Scientific significance: This result puts an important constraint for theories of critical current densities of YBCO films.

(A) A magneto-optical image of a 3-μm thick YBCO film showing a uniform magnetic field penetration.

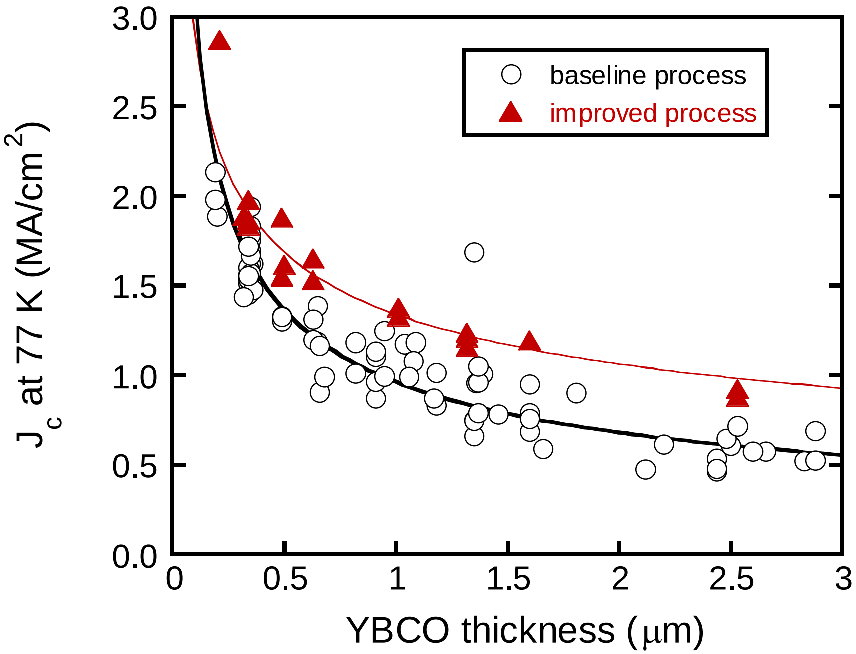
(B) $J_c(H, 77\ K)$ for three YBCO films with different thickness showing the crossover of J_c at H_r. The inset shows H_r as a function of T.

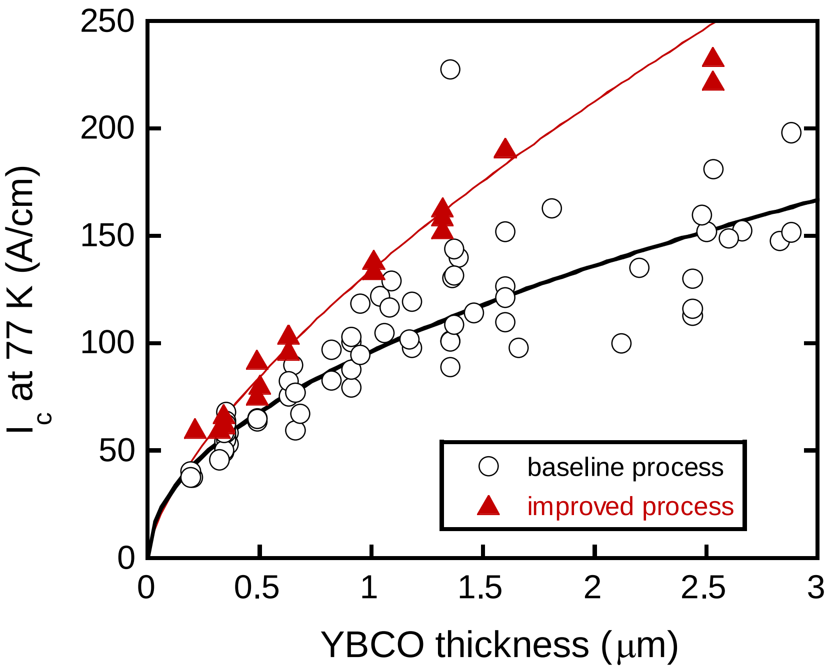
APL, **84**, 3528 (2004)

Development of high-current YBCO coated conductors

Multi-institutional Collaboration

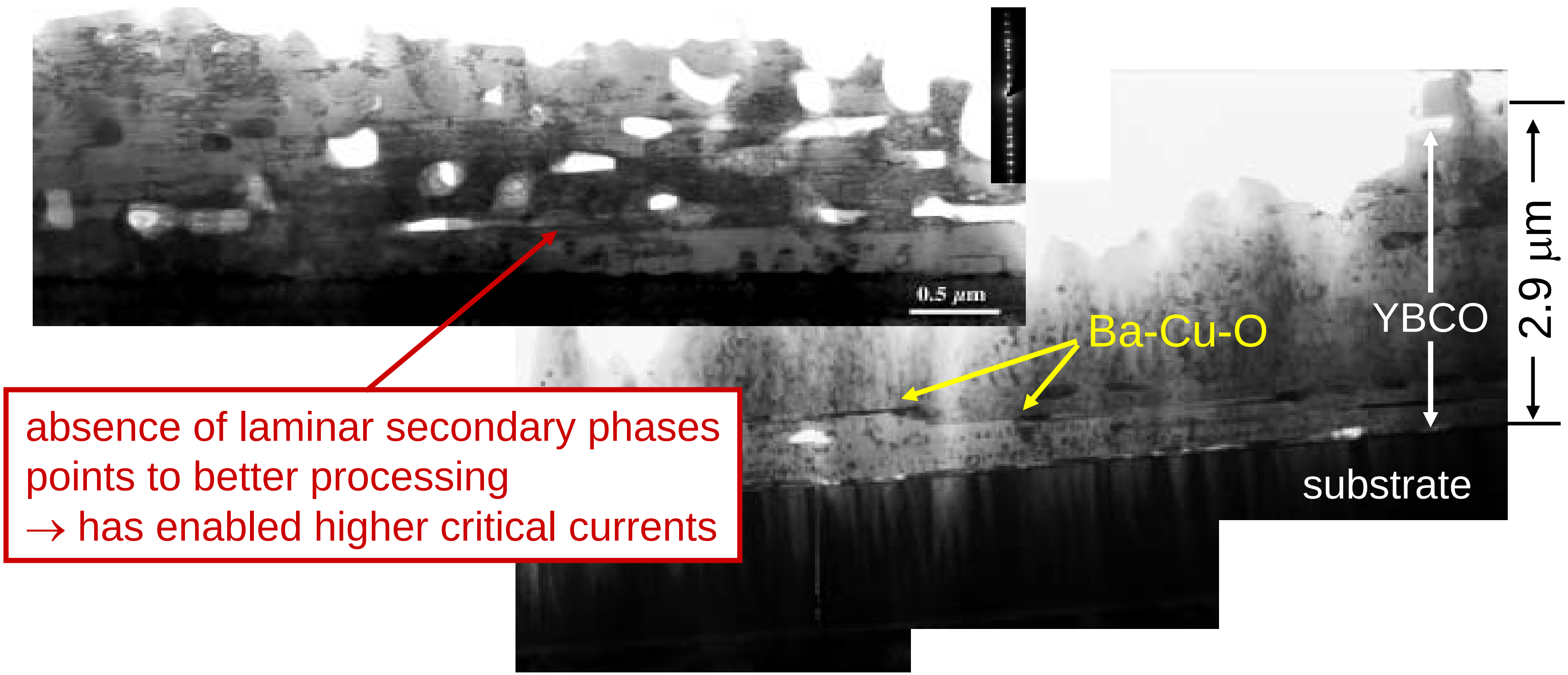
ORNL—Ron Feenstra
LANL—Terry Holesinger
Univ. Wisconsin—Matt Feldmann
ICMAB (Barcelona, Spain)—Anna Palau





Liquid-mediated growth in ex situ YBCO coatings (evaporation BaF_2 process)

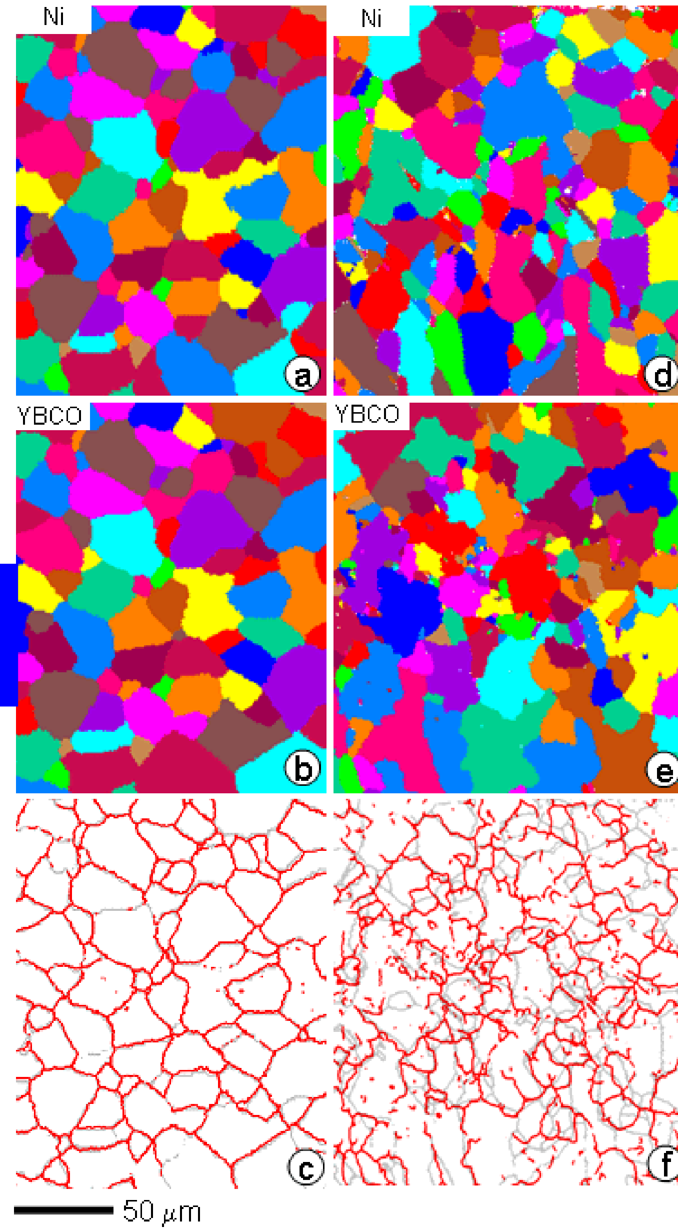
- TEM study (performed at LANL) of thick YBCO coatings (grown at ORNL) reveals a liquid-mediated, laminar growth mode
- secondary phases coat large YBCO grains in many films → reduced quality epitaxial growth in the “top of the film”
- best performance is observed for YBCO coatings without intercalated layered phases



Grain boundary overgrowth in thick YBCO conductors

- large atomic mobilities in the presence of transient liquids produce large YBCO grains
- enhanced liquid-mediated growth occurs in thick films
- perfect registry of YBCO and substrate grains does not exist in thick films
- potential benefits of grain boundary overgrowth and formation of new networks are the focus of continued study by the collaborative team

Orientation Imaging by Kikuchi electron backscatter diffraction (performed at UW)



substrate (RABiTS)

grain maps

YBCO (0.5 µm)

YBCO (2.5 µm)

grain boundary maps

YBCO (red)-substrate (gray) overlay

A New Activity in the Final Year Before "Graduation"

- Three review articles to summarize where we stand on defects and nanostructures in RE-123
  - "J_c vs. Thickness in Coated Conductors", Feenstra (ORNL), Holesinger (LANL), and Suenaga (BNL).
  - "Buffer Layers", Clem (LANL) and Paranthaman (ORNL).
  - "Oxygenation", Veal (ANL), Claus (ANL), Kramer (AMES), and Welch (BNL).

The Future After Graduation

- Numerous collaborations will continue, especially on:
  - Critical currents in coated conductors
  - Magnetic flux pinning at high magnetic fields
  - Modeling of thermodynamics, kinetics, and mechanics in coated conductors

- Some participants from this project are participants in the proposed CSP project on “High-Field Intermetallic Superconductors”